4/20/77

FERMILAB-Proposal-0548

A Search for Narrow and Broad Resonances Decaying into $K_s^o K_s^o$ and $\Lambda\bar{\Lambda}$ from $\pi^- p$ Interactions at 200 GeV/c using the Fermi MPS

K.-W. Lai* and P. Yamin

Brookhaven National Laboratory

J. Marraffino, S. Reucroft, C. Roos, M.S. Webster

Vanderbilt University

F.T. Dao, A. Mann, J. Schneps

Tufts University

T. Bowen*, E. Jenkins, R.M. Kalbach, A. Pifer

University of Arizona

J. Albright, R. Diamond, S. Hagopian, V. Hagopian, J.E. Lannutti

Florida State University

*Spokespeople

16 pgs.

548

One of the most effective ways to search for resonances in hadron interactions is to probe a definitive quantum state such as e^+e^- or $\mu^+\mu^-$ (ρ, ω, ϕ, J/Ψ, Ψ'). Due to the nature of dilepton resonances, these are restricted to the $J^P = 1^-$ system. Unexpected states such as J/Ψ and Ψ' have been discovered using this technique.

We propose to expand the search to other quantum states such as 0^+, 0^-, and 2^+ with at least an order of magnitude greater sensitivity than all other previous measurements. The reactions we plan to study are:

$$\pi^- p \rightarrow \Lambda\bar{\Lambda} + X \qquad (1)$$

$$\rightarrow K_s^o K_s^o + X \qquad (2)$$

These reactions (1) and (2) are for high-mass meson states searches. It is worth noting that the $K_s^o K_s^o$ system can only be in $J^P = 0^+, 2^+ \ldots$ states with an isospin of 0 or 1 whereas the $\Lambda\bar{\Lambda}$ system can only be in I = 0 state. We believe new, high-mass, narrow resonances in these quantum states may be uncovered which cannot be produced directly in $e^+ e^-$ collisions. The long sought after pseudoscalar $c\bar{c}$ meson, η_c, can decay into $\Lambda\bar{\Lambda}$. A rough estimate of the production cross section of such states gives the order of 2-4 μb (or $\sigma \cdot B$ 40-80 nb) at $\sim$ 200 GeV/c which is about the right estimate of our sensitivity (see Appendix I and Fig. 1).

Our aim is to reach masses of up to 15 GeV with high sensitivity in cross section (20 visible events per nb) and good mass resolution ($\sigma \sim$ 50-70 MeV or less). This represents a measurement at least one order of magnitude more sensitive than all the other previous measurements.[1] Since the MPS has demonstrated its performance and productivity in carrying out the jet experiment, we shall be brief in describing our request.

a. Beam: 600 hours with 250 pulses per hour and $2\mathrm{x}10^6$ π^- per pulse at 200 GeV/c, i.e. $3\mathrm{x}10^{11}$ π^- for the experiment.

b. Target: A 30-cm liquid hydrogen target will be used. Cylindrical MWPC's will surround the target as discussed below in section d.

c. Setup: In order to detect K_s^o and Λ with adequate efficiency, a decay region of the order of the particle's decay length is required. We have chosen 4 meters.

The LH_2 target will be immediately followed by a rectangular MPWC. This chamber defines the upstream boundary of the 4-meter decay region (which will be filled by Helium) and also serves as a veto for events where the number of prompt charged tracks is too large. MWPC's before and after the magnet will serve to reconstruct the V's. These chambers also will be used in the trigger to identify the appearance of four charged tracks after the decay region. Cylindrical MPWC's α,β surround the target and record other outgoing particles to aid in vertex location. Spark chambers follow the magnet to complete the measurement of the event. The proposed configuration is shown in Fig. 2.

d. Sensitivity: In 600 hours of running, we expect to produce 160 events/nb for the $K_s^oK_s^o$ and $\Lambda\bar{\Lambda}$ decays into charged particles. The charged decay mode correction factor of 4/9 has already been applied. The geometrical acceptance of the spectrometer corrected for a 4-meter decay volume is shown in Fig. 3, and varies smoothly between 10 and 1% as the 2-V mass goes from threshold to 10 GeV. Figure 4 shows the acceptance of the system as a function of Jackson angle.

Using an average acceptance of 10%, our net sensitivity is reduced to $\sim$ 20 detected events per nb for $K_s^oK_s^o$ and $\Lambda\bar{\Lambda}$.

e. Yield: The cross section for inclusive $\Lambda\bar{\Lambda}$ and $K^o_s K^o_s$ production as a function of the number of accompanying charged tracks has been measured in 250-GeV/c $\pi^- p$ interactions.[2] The total inclusive $\Lambda\bar{\Lambda}$ and $K^o_s K^o_s$ cross sections are 0.15 mb and 0.60 mb respectively. Requiring that the accompanying charged track multiplicity be ≤ 4, these cross sections reduce to 0.02 mb and 0.045 mb respectively. At 20 events/nb then, we expect $\sim 4\text{x}10^5$ $\Lambda\bar{\Lambda}$ events and $8\text{x}10^5$ $K^o_s K^o_s$ events. The event rate is expected to be 2 in 10^5, giving roughly 12 events/pulse. Backgrounds are discussed in the next section.

f. Trigger: Telescope counters S_A, S_B, S_C, and MWPC module BB identify an incoming beam pion. MWPC module A, immediately followed by a dE/dx counter, restricts the trigger to events with a limited number of particles entering the decay region. Cylindrical MPWC's α and β which surround the target aid in vertex location by detecting low-momentum, large-angle recoils. They may also be used to insure that an interaction has taken place in the target. Following the decay region, MWPC modules B', B, C, and D detect the additional tracks produced by the decays of the two V's. These chambers, together with the spectrometer magnet and spark chamber modules E and F, analyze the momenta of the decay tracks.

g. Event Rate and Background: Preliminary results obtained from the Chicago Circle (E110) group indicate a substantial hadronic background. A trigger consisting of 1 charged track entering a "decay region" and the subsequent appearance of two V's was dominated by beam interactions in chambers and air. The signal-to-noise ratio was 1:30. Demanding that an interaction take place in the target by requiring a hit in chambers α and β only reduced this to 1:10. (The singles rates in these chambers were very high, so accidental coincidences formed a substantial part of this trigger.)

548

E110 ran with 0.3 g/cm^2 of material in their "decay region." By installing a helium bag and by placing the dE/dx counter after MWPC module A, we would expect to have 0.1 g/cm^2 in our 4-meter decay region. Thus we might expect a signal-to-noise ratio of about 1:3 for events with a single charged particle entering the decay region. Events with 2 or more particles entering the region are almost certainly sure to arise from real interactions in the target and, as E110 found, are significantly cleaner. Overall, then, we might expect our noise to be about 2.5 times the real event rate for the following triggers:

Hit in α,β	Number of Charged Particles Entering Region	Number of Charged Particles Leaving Region
No	0	4
Yes	1	5
No	2	6
No	3	7

With a true event rate of 12/pulse we would thus expect 42 triggers per pulse. The 30 ms dead time of the spark chambers limits the actual rate to about 26/pulse. We therefore require 600 hours of running, at 250 pulses/hour, to acquire our data.

References

1. W. Beusch *et al.*, Physics Letters **25B**, 357 (1967); Physics Letters **28B**, 211 (1968).
2. D. Bogert, et al., Fermilab preprint, 3/18/77.

Appendix I

Search for η_c at the MPS

Assuming that the J is a $c\bar{c}$ bound state, we suggest searching for the η_c, its pseudoscalar partner, in $\pi^- p$ interactions at 200 GeV/c. We consider in particular

$$\pi^- p \to \eta_c X \qquad \eta_c \to \Lambda\bar{\Lambda}. \tag{1}$$

Using the MPS as a detector, one could reach a sensitivity of 10 events/nb for this reaction. The cross-section for production of the η_c is not known, nor can it be reliably calculated. However, a reasonable estimate (see below) gives a $\sigma \cdot B$ of the order of 40–80 nb. This value is about the level at which we would expect to begin to see a significant signal above background.

The reaction $pp \to JX \to e^+e^-X$ has, of course, been observed at the Fermi Lab. Using the experimental cross section and the branching ratio[1] for $J \to e^+e^-$ of 7%, one finds

$$\sigma(pp \to JX) \approx 200 \text{ nb at } 200 \text{ GeV/c}. \tag{2}$$

To estimate the η_c cross section we can clearly write

$$\sigma(\pi^- p \to \eta_c X) = \frac{\sigma(\pi^- p \to \eta_c X)}{\sigma(\pi^- p \to JX)} \frac{\sigma(\pi^- p \to JX)}{\sigma(pp \to JX)} \sigma(pp \to JX) \tag{3}$$

We expect that both the η_c and the J will be formed by the annihilation of an ordinary $q\bar{q}$ quark pair through gluons to form a $c\bar{c}$ pair. See Fig. 1. The main difference is that the J must be formed through three gluons because its spin-parity is 1^-, while the η_c can be formed through two gluons. Thus the cross section for the J is smaller by $O(\alpha_s^2)$, where $\alpha_s = q_s^2/4\pi$ is the effective gluon coupling constant. Exactly this difference has been used by several authors to find the relative hadronic widths of the η_c and the J by calculating their couplings to $q\bar{q}$. Schnitzer[2] finds

$$\frac{\Gamma(\eta_c \to \text{had.})}{\Gamma(J \to \text{had.})} = 70, \tag{4}$$

while Appelquist in a review[3] of several calculations gives

$$\frac{\Gamma(\eta_c \to \text{had.})}{\Gamma(J \to \text{had.})} \approx 100. \tag{5}$$

As a check we can use the estimate of α_s by Barnett, Georgi, and Palitzer[4] to compute

$$\frac{\Gamma(\eta_c \to \text{had.})}{\Gamma(J \to \text{had.})} \sim \frac{1}{\left(\frac{\alpha_s}{\pi}\right)^2} = 50. \tag{6}$$

Thus let us take

$$\frac{\sigma(\pi^- p \to \eta_c X)}{\sigma(\pi^- p \to JX)} \gtrsim \frac{\Gamma(\eta_c \to \text{had.})}{\Gamma(J \to \text{had.})} \approx 50 - 100 \tag{7}$$

We can estimate the second factor in Eq. 4 from experiment. We know that at FNAL energies[5]

$$\frac{\sigma(\pi^- p \to JX)}{\sigma(pp \to JX)} \approx 2. \tag{8}$$

Then

$$\sigma(\pi^- p \to \eta_c X) \simeq (50\text{–}100) \times 2 \times 200 \text{ nb}$$

$$\simeq 20\text{–}40 \ \mu\text{b}. \tag{9}$$

The branching ratio for $\eta_c \to \Lambda\bar{\Lambda}$ is of course not known, but there is no reason to suppose that it is less than that for $J \to \Lambda\bar{\Lambda}$:

$B(\eta_c \to \Lambda\bar{\Lambda}) = B(J \to \Lambda\bar{\Lambda}) \simeq 0.2\%$[1] giving $\sigma \cdot B$ 40–80 nb and

$B(\eta_c \to \Lambda\Lambda)$ could be as high as 1.0%, giving $\sigma \cdot B \approx 200$ to 400 nb.

It is important to note that η_c cannot be produced by e^+e^- annihilation process directly. We also understand that the detection efficiency of the SPEAR for two V^o's is less than a few percent.

References:

1. G.S. Abrams, Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford University, August 21-27, 1975, Ed. W.T. Kirk, p. 25.

2. H.J. Schnitzer, Lectures on New Particle Spectroscopy, BNL, August 1976.

3. T. Appelquist, "Comments on the New Particles", Invited talk presented at the 2nd International Conference at Vanderbilt University on New Results in High Energy Physics, Nashville, Tennessee, March 1-3, 1976. Yale Report COO-3075-141.

4. R.M. Bennett, H. Georgi, H.D. Politzer, Harvard Preprint, July 1976.

5. G.J. Blanar et al., Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford University, August 21-27, 1975, Ed. W.T. Kirk, p. 195.

6. S.C.C. Ting, Proceedings of the 1975 International Symposium on Lepton and Photon Interactions at High Energies, Stanford University, August 21-27, 1975, Ed. W.T. Kirk, p. 155.

4A 548

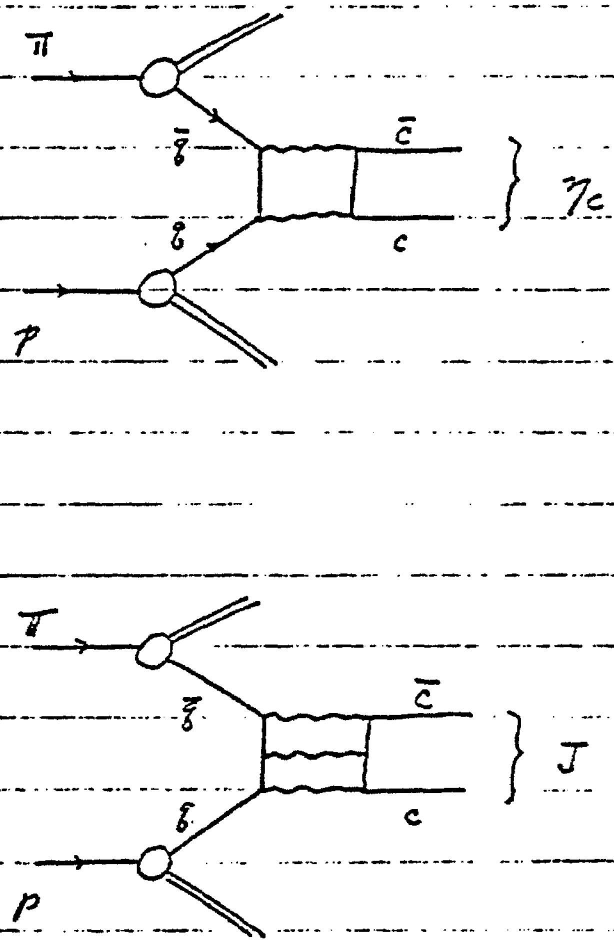


Figure 1: Production mechanisms for η_c and J.

APPENDIX II

A simple estimate of yield for two (of many) particles of current interest.

1. The η_c

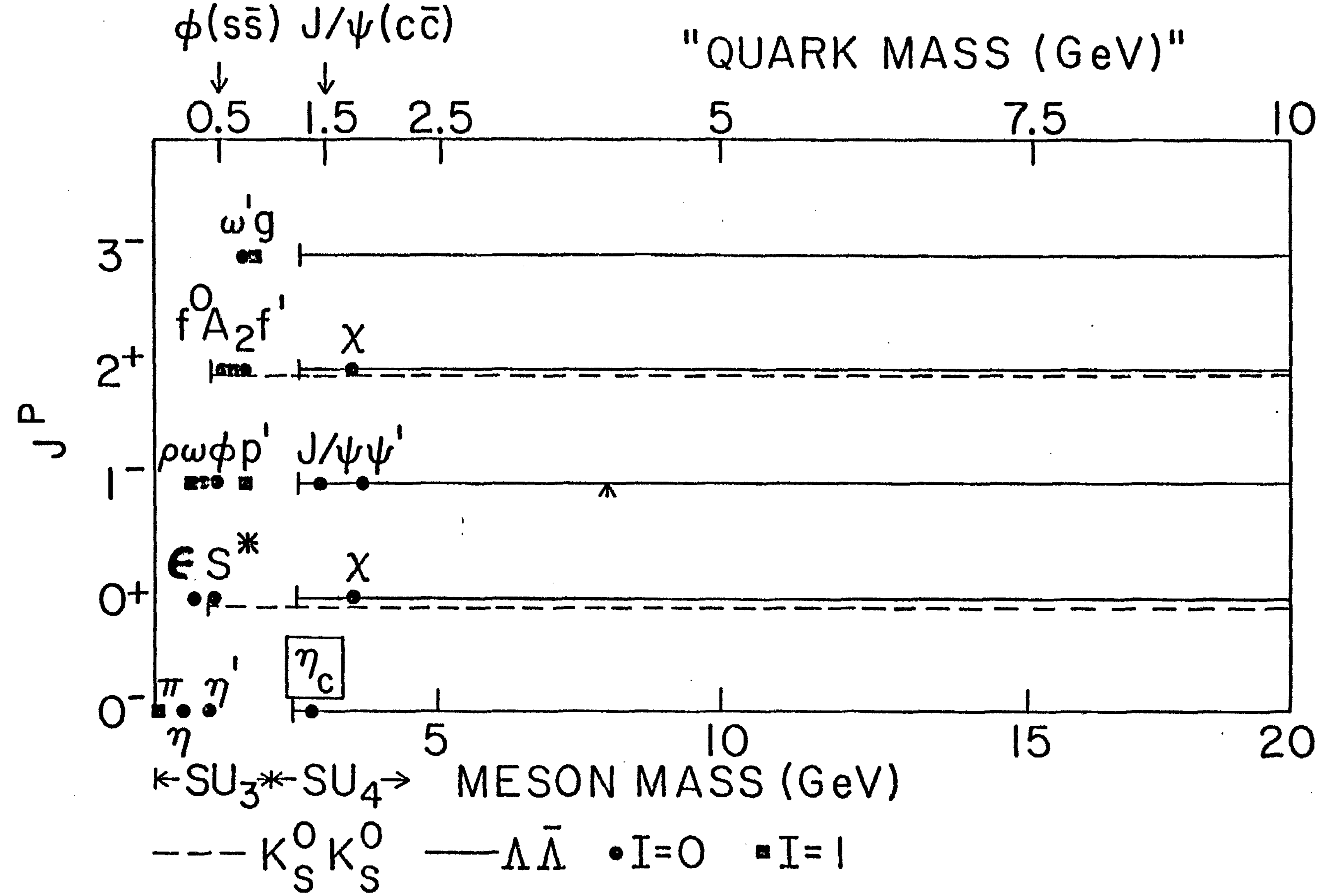
As discussed in Appendix I, the product of cross section times branching ratio into $\Lambda\bar{\Lambda}$ is of the order of 40-80 nb. Since our sensitivity is 20 events/nb, we could see as many as 400-800 of these particles.[5] However, our trigger excludes events with large numbers of forward charged particles, so the actual number of η_c's is likely to be somewhat less.

2. A recent report from a Fermilab group (B. Cox <u>et al</u>.) suggests the presence of another new particle in $\gamma\gamma$ final states at 3.9 GeV. For brevity, we will refer to this object as the C. Cox reports that $\sigma \cdot B_{\gamma\gamma} \simeq 60$ nb. If we assume that $\sigma \cdot B_{\Lambda\bar{\Lambda}}$ is of the same order, then we expect as many as 600 such events, but the multiplicity requirement in the trigger will reduce this number too.

If C is 0^- can go only $\Lambda\bar{\Lambda}$ 600 events;

If C is 0^+ can go either $\Lambda\bar{\Lambda}$ or $K_s^o K_s^o$

expect $\sim 2 \times 600 \simeq 1200$ events.

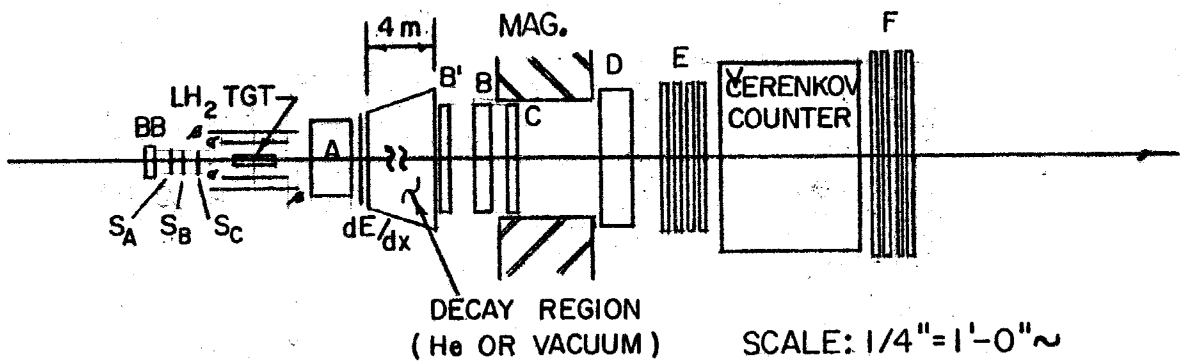


φ(ss̄) J/ψ(cc̄)
"QUARK MASS (GeV)"
0.5
1.5
2.5
5
7.5
10
J^P
3⁻
2⁺
1⁻
0⁺
0⁻
ω' g
f⁰ A₂ f'
χ
ρωφ p'
J/ψ ψ'
ε S*
χ
π η'
η
η_c
5
10
15
20
←SU₃*←SU₄→
MESON MASS (GeV)
- - - $K^0_S K^0_S$
—— $\Lambda\bar{\Lambda}$
• I=0
▪ I=1

FIG. 1

548

FERMILAB MPS CONFIGURED FOR
$2V^{\circ}$ EXPERIMENT



LEGEND

A, B, BB, B', C, D - PLANAR PWC'S
α, β, - CYLINDRICAL PWC'S
S_A, S_B, S_C, - BEAM TELESCOPE COUNTERS
dE/dx - dE/dx COUNTER
E, F - SPARK CHAMBER MODULES

FIG. 2

2-548

3-548

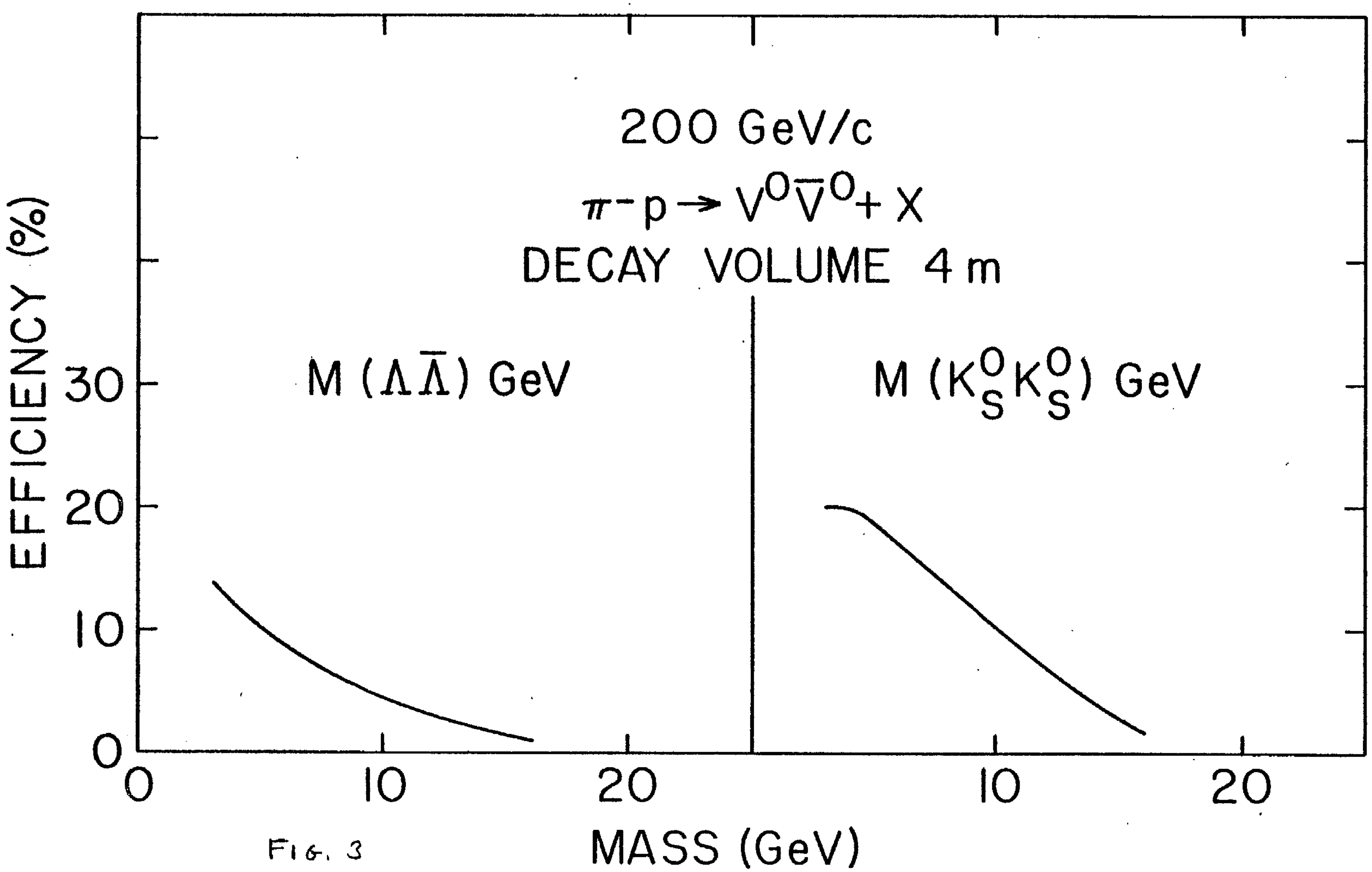
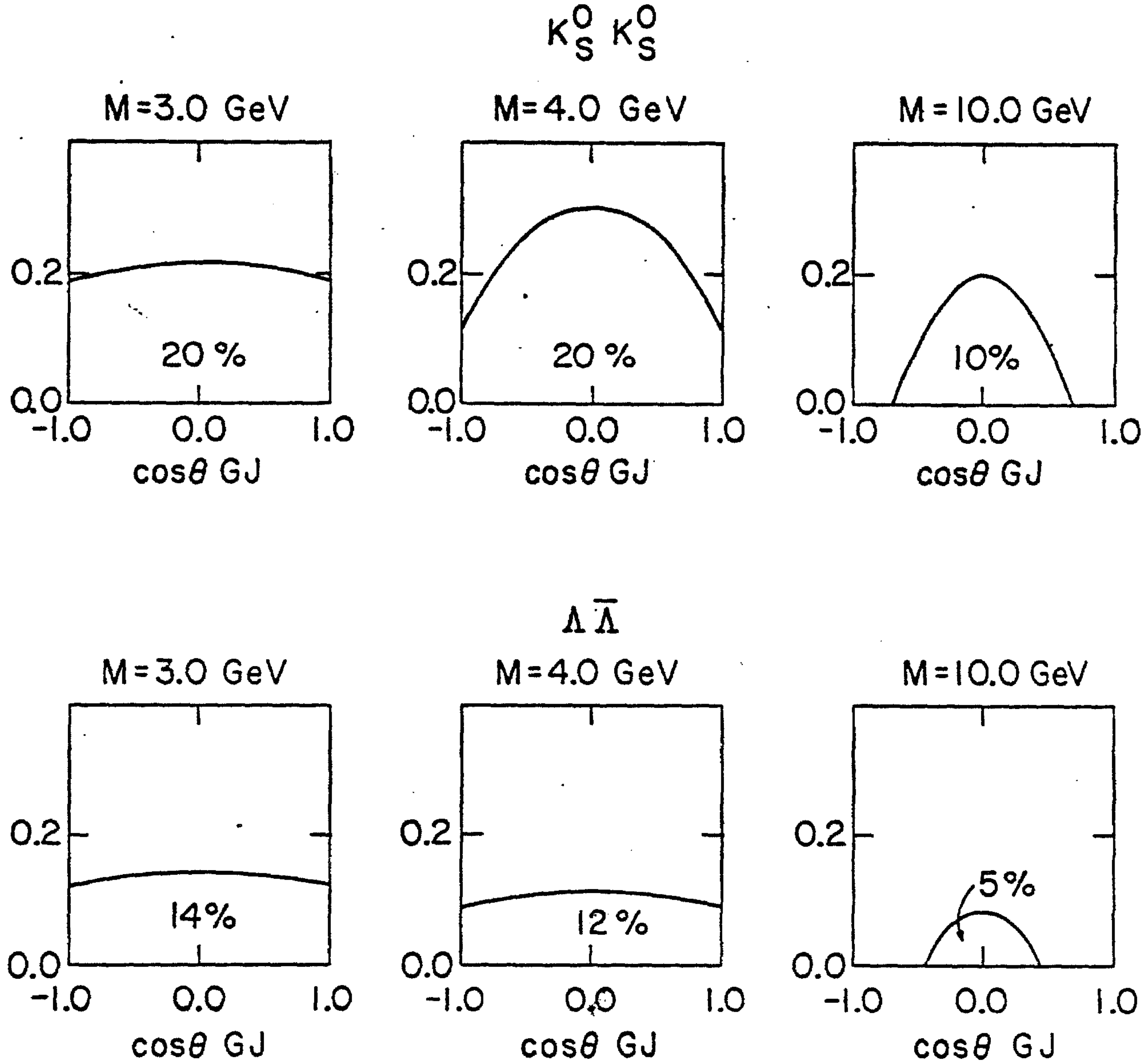

200 GeV/c
$\pi^- p \rightarrow V^0 \overline{V}^0 + X$
DECAY VOLUME 4 m
M $(\Lambda\overline{\Lambda})$ GeV
M $(K_S^0 K_S^0)$ GeV
EFFICIENCY (%)
0
10
20
30
0
10
20
10
20
MASS (GeV)

FIG. 3



$K^0_S\, K^0_S$
M=3.0 GeV
M=4.0 GeV
M=10.0 GeV
0.2
0.0
-1.0
0.0
1.0
cosθ GJ
20 %
20 %
10%
$\Lambda\,\bar{\Lambda}$
14%
12 %
5%

figure 4